ANNEX G

DAM FAILURES

I. TYPE OF HAZARD

Dam Failures

II. DESCRIPTION OF HAZARD

Over the years dam failures have injured or killed thousands of people, and caused billions of dollars of property damage in the United States. Among the most catastrophic were the failures of the Teton Dam in Idaho in 1976, which killed 14 people and caused more than $1 billion in damage, and the Kelly-Barnes Dam in Georgia, which left 39 dead and $30 million in property damage. In the past few years, over 200 documented dam failures occurred nationwide causing four deaths and millions in property damage and repair costs. The problem of unsafe dams in Missouri was underscored by dam failures at Lawrenceton in 1968, Washington County in 1975, Fredricktown in 1977, and a near failure in Franklin County in 1979. More recently, a severe rainstorm and flash flooding in October 1998 compromised about a dozen small, unregulated dams in the Kansas City area. Overall, many of Missouri's smaller dams are becoming a greater hazard as they continue to age and deteriorate. While hundreds of them need to be rehabilitated, lack of funding and questions of ownership loom as obstacles.

A dam is defined by the National Dam Safety Act as an artificial barrier that impounds or diverts water and (1) is more than 6 feet high and stores 50 acre feet or more, or (2) is 25 feet or more high and stores more than 15 acre feet. Based on this definition, there are over 80,000 dams in the United States. Over 95 percent of these dams are non-federal, with most being owned by state governments, municipalities, watershed districts, industries, lake associations, land developers, and private citizens. Dam owners have primary responsibility for the safe design, operation, and maintenance of their dams. They also have responsibility for providing early warning of problems at the dam, for developing an effective emergency action plan, and for coordinating that plan with local officials. The State has ultimate responsibility for public safety; many states regulate construction, modification, maintenance, and operation of dams, and also implement a dam safety program.

Dams can fail for many reasons. The most common are as follows:

1. Piping: Internal erosion caused by embankment leakage, foundation leakage and deterioration of pertinent structures appended to the dam

2. Erosion: Inadequate spillway capacity causing overtopping of the dam, flow erosion, and inadequate slope protection

3. Structural Failure: Caused by an earthquake, slope instability or faulty construction

These three types of failures are often interrelated. For example, erosion, either on the surface or internal, may weaken the dam and lead to structural failure, whereas a structural failure may shorten the seepage path and lead to a piping failure. Observable defects that provide good evidence of potential dam failures are illustrated in Section VII of this annex.

Dam construction varies widely throughout the state. Most dams are of earthen construction. Missouri's mining industry has produced numerous tailing dams for the surface disposal of mine waste. These dams are made from mining material deposited in slurry form in an impoundment. Other types of earthen dams are reinforced with a core of concrete or asphalt. The largest dams in the state are built of reinforced concrete and are used for hydroelectric power.

III. HISTORICAL STATISTICS

Missouri had some 4,100 recorded dams in July 2003, the largest number of man-made dams of any state in the United States. The topography of the state allows lakes to be built easily and inexpensively, which accounts for the high number. Despite such a large number, only about 620 Missouri dams (about 20 percent) fall under state regulations, while another 85 dams are federally controlled. A non-federal dam can be anything from a large farm pond (e.g., MFA Research Farm Lake Dam in Saline County, which is 20 feet high and holds back 60 acre feet of water) to Bagnell Dam, which created the Lake of the Ozarks. Most non-federal dams are privately owned structures built either for agricultural or recreational use. Missouri also has some 600 dams that were built as small watershed projects under Public Law-566 (Watershed Protection and Flood Prevention Act of 1953). These dams serve many functions, including flood control, erosion control, recreation, fish and wildlife habitat, water supply, and water quality improvement. Many of these PL-566 dams need ongoing maintenance to safely provide these functions. Another group of older dams in the state were originally built by railroad companies as holding ponds for water to be used in steam locomotives. Many of these are now used as drinking water reservoirs by nearby towns and cities.

Within the State of Missouri, the Department of Natural Resources Division of Geology and Land Survey maintains a Dam and Safety Program. The objective is to ensure that dams are safely constructed, operated, and maintained pursuant to Chapter 236 Revised Statutes of Missouri. Under that law, a dam must be 35 feet or higher to be state regulated. These dams are surveyed by state inspectors at least every 5 years. However, most Missouri dams are less than 35 feet high and thus, are not regulated. While the State has for many years encouraged dam owners to inspect those unregulated dams, the condition of some of these small structures may be inadequate.

IV. MEASURE OF PROBABILITY AND SEVERITY

Dams are generally classified in three categories that identify the potential hazard to life and property should a failure occur:

1. High Hazard: If the dam were to fail, lives would be lost and extensive property damage could result.

2. Significant Hazard: Failure could result in the loss of life and appreciable property damage.

3. Low Hazard: Failure results in only minimal property damage.

Table G-2 breaks down the number of dams by county and indicates the hazard potential classification of those dams in that county.

A. Status of Missouri Privately-Owned Dams

According to the MDNR 2003 Missouri Dam Database, 622 dams, or 15 percent of the dams surveyed, had a high hazard potential, while 992 dams, or 25 percent of the dams surveyed had a significant hazard potential. Another 2,402 dams, or 60 percent of the dams surveyed had a low hazard potential. However, many of Missouri's unregulated, private dams have gone unchecked for decades, according to Jim Alexander, chief engineer for MDNR's dam safety program. Dams that don't get regular attention can erode over the years, or be damaged by floods, he notes. "There are accidents out there waiting to happen." Some of the potential hazardous dams are 5 miles from a downstream city. If a dam fails, the owner is still responsible for damage, Alexender says, "but there's no legal handle on them to maintain the dams." Information collected from the Corps of Engineers 1980 National Inventory of Dams is outdated, and ownership of unregulated dams may have changed. Concern is mounting even for some of the state's regulated dams; particularly the Silver Creek Dam east of Rockaway Beach in Taney County, where the ownership is unknown. Erosion is eating away at the 40-foot-high dam, and the runoff creates silt deposits along the shore of Lake Taneycomo. One end of the dam is a barren clay bank that could give way during a heavy rainstorm, Alexander says. MDNR's plans were to obtain money through the State Legislature to repair the dam, and have the Attorney General's Office seek reimbursement from the owner when that person is identified.

B. Missouri's Small Watershed Projects with Dams

In 1954, Missouri built its first small watershed dam, and today has over 600 built under PL-566. These dams vary in size and perform multiple functions, including flood and erosion control. Many have a designed life of 50 years. According to a 1999 report, about 25 of these dams are more than 40 years old, and most will need major rehabilitation soon. More than 130 dams are 30 to 39 years old, while 182 of them are 20 to 29 years old (see Figure G-3, in Section VII).

The Iowa Watershed Task Force published a series of case studies in 1999 on aging watershed dams. The Missouri case study on the Tabo Creek Watershed Project in Lafayette County best illustrates the range of problems. The Tabo Creek project was authorized in 1960, with the first dam constructed in 1961. Since then, 64 grade-stabilization dams have been installed. Many of these dams now face the same problems that plague older dams in other watersheds approaching the end of their 50-year design life. They include deteriorating pipes and sediment filling the reservoirs. The most common problem is decaying pipes, since 44 of the dams were installed with corrugated metal pipes. One of the most visible problems is the lakes filling with sediment. The Lafayette County Soil and Water Conversation District is responsible for operation and maintenance, and performs annual inspections of each structure. However, the local sponsors don't have the funds needed to rehabilitate all the structures, which would cost an estimated $6 million, the case study notes. To date, no dams built under the Small Watershed Program anywhere in the U.S. have failed and resulted in loss of life or property. However, some exhibited significant problems that were corrected before a catastrophic failure or tragedy has occurred. The chances of such occurrences will undoubtedly increase, as the dams get older.

C. U.S. Army Corps of Engineers Operated Reservoir Dams in Missouri

The U.S. Army Corps of Engineers operates and maintains nearly a dozen large federally regulated reservoir dams in Missouri through its Kansas City, St. Louis, and Little Rock Districts. Extensive care is taken by the Corps in the design, construction, and operation of their dams. As a result, the Corps record for dam safety is considered excellent. Nevertheless, dam failures elsewhere in the country raise the possibility that any one of these facilities could fail. The threat

of an earthquake in some areas of the state, the possibility of sabotage or terrorist activities, or other natural or technological events are among the potential risk factors that could cause such a structure to fail.

For its regulated dams, the Corps Kansas City District began a program in1999 to revise its Contingency Plans for seven district dams it operates in Missouri. The plans were republished as emergency action plans, to provide an updated emergency notification/points of contact list in the event of a dam failure; to provide for increased communications with local emergency management officials; and to provide a more simplified format for clarity. The Corps Kansas City District worked jointly with the State Emergency Management Agency (SEMA), the National Weather Service, and local officials, including the county sheriff and emergency management coordinator in the affected counties (24 hours below stream). The plans were updated for Pomme de Terre Dam (Hickory and Benton counties); Blue Springs Dam (Jackson County); Longview Dam (Jackson County); Smithville Dam (Clay and Platte Counties); Long Branch Dam (Macon and Randolph Counties); Stockton Dam (Cedar and St. Clair Counties); and Truman Dam (Benton and Morgan Counties). Two other counties, Schuyler and Putnam, were included in an updated plan for the Corps' Rathbun Dam in Iowa.

The Corps St. Louis District maintains flood emergency plans for its Clarence Cannon Dam/Mark Twain Lake project, with the plan covering Ralls, Monroe, Pike and Shelby Counties; and Lake Wappapello Dam for Wayne, Butler, Stoddard and Dunklin Counties. The Corps Little Rock District has similar plans for Table Rock Dam, Taney and Ozark Counties; and for Clearwater Dam, Wayne, Butler, and Reynolds Counties. Figure G-4 shows the location of the Corps' Missouri reservoir dams by county, and adjacent counties that could be impacted (emergency notification) by a dam failure.

Missouri's percentage of high hazard dams in the MDNR inventory puts the State at about the national average for that category. However, the probability of dam failure increases as many of the smaller and privately-owned dams continue to deteriorate without the benefit of further regulation or improvements. Based on this information, the State rates the overall probability of dam failure as significant and the severity as moderate.

V. IMPACT OF THE HAZARD

When a dam fails, the stored water can be suddenly released and have catastrophic effects on life and property downstream. Homes, bridges, and roads can be demolished in minutes. The failure of the Buffalo Creek Dam in 1972 in West Virginia killed 125 people. Should the Silver Creek Dam in Taney County fail, for example, the ensuing flood would likely take out a section of Missouri Highway 176, endanger other structures, and dump tons of silt into the lake. At least 26 recorded dam failures have occurred in 20 Missouri counties since the turn of the 20th century. Fortunately, only one drowning has been associated with a dam failure in the state, and there has been little consequence to property.

Residents near a high or moderate hazard dam should become familiar with the dam's emergency action plans. Emergency plans written for dams include procedures for notification and coordination with local law enforcement and other governmental agencies, information on the potential inundation area, plans for warning and evacuation, and procedures for making emergency repairs.

VI. SYNOPSIS

Dam breaks are caused most often by failure of the structure itself. However, flooding is the most common hazard associated with dam failure. Prolonged rains and flooding can saturate earthen dams, for example, producing much the same breaching effect as occurs with earthen levees. Flooding can also result in overtopping of dams when the spillway and reservoir storage capacities are exceeded. A large slide may develop in either the upstream or downstream slope of the embankment and threaten to release the impounded water. Complete structural collapse can occur, especially as a result of an earthquake.

Actual dam failure can result not only in loss of life, but also considerable loss of capital investment, loss of income, and property damage. Loss of the reservoir itself can cause hardship for those dependent on it for their livelihood or water supply.

VII. MAPS OR OTHER ATTACHMENTS

Tables:

- Dams In Missouri By Purpose: Table G-1.
- Dams in Missouri by County and the Threat of Dam Failure in Each County: Table G-2.

Illustrations:

- Observable Defects: Figure G-1.
- Number of Dams By County: Figure G-2.
- Our Aging Dams – Survey of Small Watershed Dams (Missouri and national summaries): Figure G-3.
- Missouri Counties with Corps of Engineers Reservoir Dams: Figure G-4.

TABLE G-1

DAMS IN MISSOURI BY PURPOSE

Purpose	Number	Percent
Fire and Farm Ponds	381	10.8
Flood Control	285	8.0
Hydroelectric	8	0.2
Irrigation	296	8.4
Navigation	7	0.2
Recreation	1,826	51.6
Tailings and Others	487	13.8
Water Supply	243	6.9
Undetermined	8	0.1

TABLE G-2

DAMS IN MISSOURI BY COUNTY AND THE THREAT OF DAM FAILURE IN EACH COUNTY

County	Number of Dams	Hazard Potential Classification		
		High	Significant	Low
Adair	27	2	6	19
Andrew	22	4	7	11
Atchison	10	1	1	8
Audrain	85	5	23	57
Barry	1	0	0	1
Barton	31	0	4	27
Bates	23	2	7	14
Benton	25	3	5	17
Bollinger	27	4	8	15
Boone	123	28	26	69
Buchanan	29	5	8	16
Butler	30	1	8	21
Caldwell	18	1	4	13
Callaway	107	9	24	74
Camden	21	5	6	10
Cape Girardeau	29	12	4	13
Carroll	46	1	8	37
Carter	13	1	4	8
Cass	67	13	18	35
Cedar	11	1	1	9
Chariton	24	1	2	21
Christian	4	0	1	3
Clark	33	2	3	28

TABLE G-2 (Continued)

DAMS IN MISSOURI BY COUNTY AND THE THREAT OF DAM FAILURE IN EACH COUNTY

County	Number of Dams	Hazard Potential Classification		
		High	Significant	Low
Clay	36	9	10	17
Clinton	25	1	7	17
Cole	30	5	15	10
Cooper	22	0	2	20
Crawford	76	8	21	47
Dade	11	0	1	10
Dallas	4	0	1	3
DeKalb	60	2	17	41
Dent	36	6	10	20
Douglas	5	0	2	3
Dunklin	2	1	1	0
Franklin	137	22	32	83
Gasconade	80	8	14	58
Gentry	19	1	4	14
Greene	18	10	3	5
Grundy	36	4	6	26
Harrison	112	2	44	64
Henry	39	0	6	33
Hickory	7	1	1	5
Holt	18	3	4	11
Howard	33	5	2	25
Howell	24	2	7	15
Iron	41	14	8	19
Jackson	77	27	18	32
Jasper	14	2	3	9
Jefferson	149	60	48	41
Johnson	92	10	14	68
Knox	21	0	6	15
Laclede	18	0	7	11
Lafayette	187	2	41	144
Lawrence	7	0	0	7
Lewis	67	0	16	51
Lincoln	67	7	23	37
Linn	17	2	6	9
Livingston	59	1	16	42
McDonald	3	1	0	2
Macon	24	3	3	18
Madison	24	12	8	4
Maries	29	0	7	22

TABLE G-2 (Continued)

DAMS IN MISSOURI BY COUNTY AND THE THREAT OF DAM FAILURE IN EACH COUNTY

County	Number of Dams	Hazard Potential Classification		
		High	Significant	Low
Marion	21	1	4	16
Miller	14	4	4	6
Mississippi	3	0	0	3
Moniteau	19	2	4	13
Monroe	24	2	5	17
Montgomery	84	10	18	55
Morgan	12	0	2	10
New Madrid	1	0	0	1
Newton	15	6	4	5
Nodaway	52	1	12	39
Oregon	9	2	1	6
Osage	21	3	10	8
Ozark	7	1	4	2
Pemiscot	3	0	0	3
Perry	32	12	7	13
Pettis	28	3	4	21
Phelps	29	4	8	17
Pike	46	2	16	28
Platte	26	7	8	10
Polk	13	0	2	11
Pulaski	14	0	0	14
Putnam	17	0	5	12
Ralls	29	5	8	16
Randolph	45	3	9	32
Ray	38	10	9	19
Reynolds	22	12	2	8
Ripley	24	0	8	16
St. Charles	113	19	28	65
St. Clair	15	0	1	14
St. Francois	63	20	23	20
Ste. Genevieve	50	18	16	16
St. Louis	42	22	14	6
St. Louis City	1	0	1	0
Saline	23	2	4	17
Scotland	22	3	2	17
Scott	16	3	2	11
Shannon	9	1	3	5
Shelby	23	2	5	16
Stoddard	26	8	5	13

TABLE G-2 (Continued)

DAMS IN MISSOURI BY COUNTY AND THE THREAT OF DAM FAILURE IN EACH COUNTY

County	Number of Dams	Hazard Potential Classification		
		High	Significant	Low
Stone	1	1	0	0
Sullivan	40	1	7	32
Taney	7	3	1	3
Texas	6	0	2	4
Vernon	43	1	5	37
Warren	125	28	46	51
Washington	119	51	34	34
Wayne	34	15	9	10
Webster	19	1	9	9
Worth	35	1	3	31
Wright	12	0	6	6

FIGURE G-1

OBSERVABLE DEFECTS

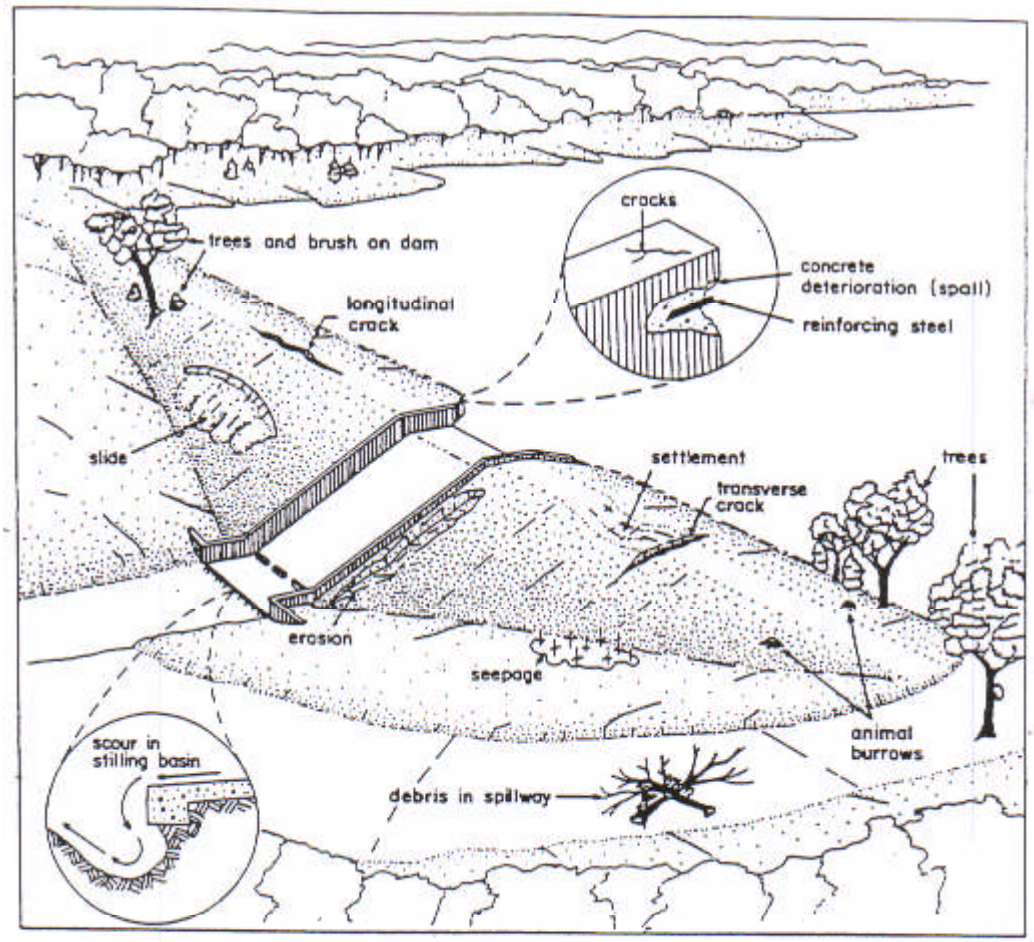
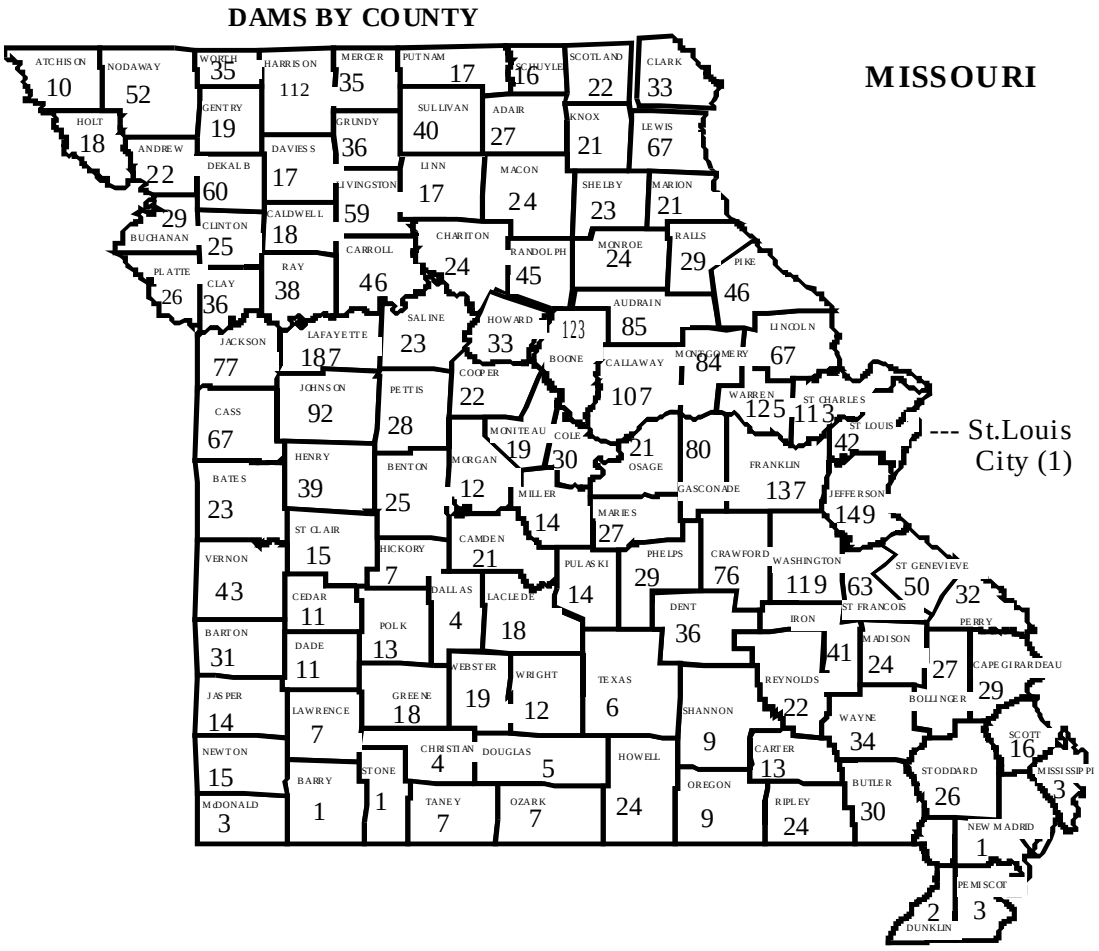


FIGURE G-2

NUMBER OF DAMS BY COUNTY

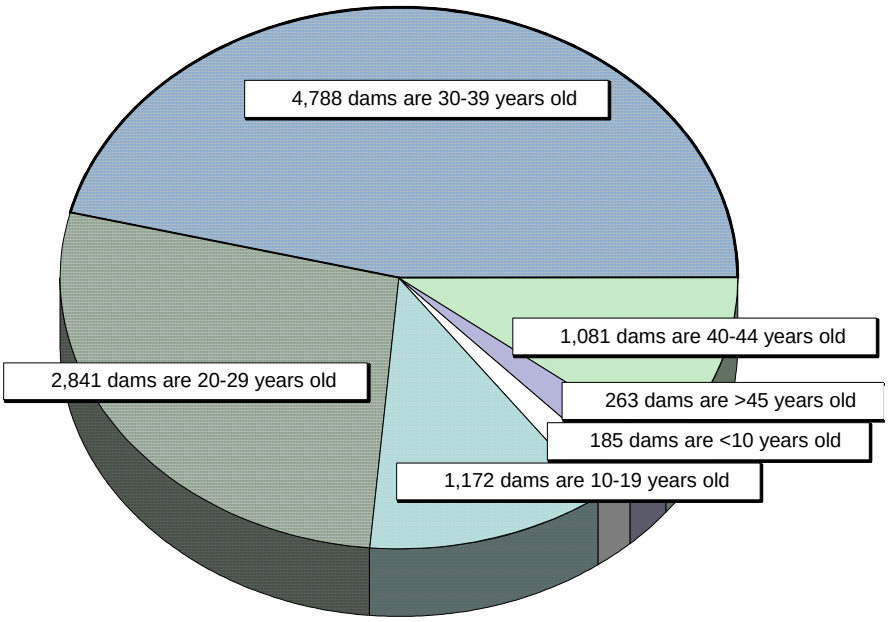


Source: Inventory of Dams, Department of Natural Resources, Division of Dam Safety

FIGURE G-3

OUR AGING DAMS
SURVEY OF SMALL WATERSHED DAMS

NATIONWIDE



MISSOURI

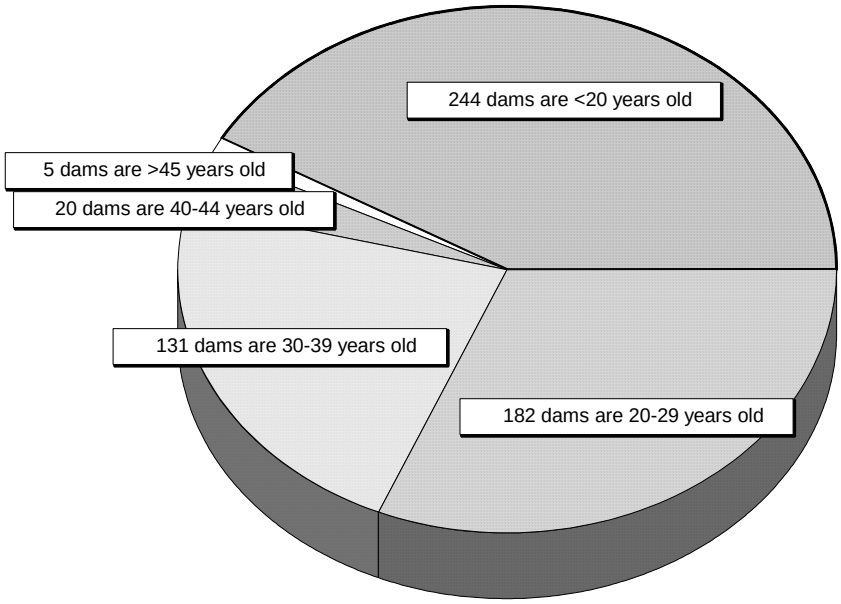


FIGURE G-4

MISSOURI COUNTIES WITH CORPS OF ENGINEERS RESERVOIR DAMS

In the event of a dam failure, emergency warning/notification procedures are provided in both Corps of Engineers flood emergency plans and local county emergency operations plans to alert local officials in the threatened areas. Emergency notification includes the county in which the dam is located, and adjacent/nearby counties below stream that may also be impacted. The Corps maintains such emergency plans for each individual dam, and copies are kept on file with the State Emergency Management Agency.

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